# Appendix G
# 2020 Bathymetric Survey Data Report

**Prepared by Northwest Hydro, Inc. and Anchor QEA, LLC**

# 1   Introduction and Survey Design

The 2019 Survey Quality Assurance Project Plan (QAPP) described required bathymetric surveying coverage, methods, and quality control for the Lower Duwamish Waterway (LDW) upper reach (Anchor QEA and Windward 2019). The 2019 bathymetric survey of the upper reach collected precision bathymetry data between River Mile (RM) 2.75 and RM 5.25. Two different survey-grade sonar systems were used to accurately map the project area and produce the final surface model of the LDW. The primary sonar system that collected a majority of the project bathymetry was a high-resolution multibeam sonar system. A single-beam sonar system was used in a few shallow intertidal areas that were too shallow for safe operation of the multibeam system. The 2019 survey results were reported in Appendix A of the Phase I Pre-Design Investigation (PDI) QAPP. Appendix A noted that there were limited data gaps in the 2019 survey coverage, due to the presence of large barges or vessels, that would be surveyed to fill in those data gap areas during the Phase I PDI in 2020.

This report summarizes the 2020 bathymetric survey to fill in data gaps in survey coverage. It supplements the 2019 survey report by providing additional details on surveying methods, quality control, and data processing methods that were used for the both the 2019 and 2020 bathymetric surveys. There were no deviations from the Survey QAPP during the 2020 bathymetric survey. Bathymetric survey coverage in the upper reach is complete and no additional coverage data gaps exist. The final combined bathymetric data were used to create a digital terrain model of the seafloor morphology, from which contours and sun-illuminated images were generated.

Both the 2019 and 2020 surveys were conducted on an established coordinate system. All bathymetry data are referenced to monuments established by the Anchor QEA project team prior to bathymetry data acquisition. The horizontal datum for this survey is North American Datum of 1983, 1991 adjustment (NAD83/91), State Plane Coordinate System, Washington North Zone, measured in U.S. Survey Feet; the vertical datum for this survey is mean lower low water (MLLW). The 2019 bathymetric survey was conducted between April and May 2019. For the 2020 bathymetric survey, hydrographic survey operations were conducted on June 15 and 16, 2020. Data acquisition was performed during higher daylight tides to maximize bathymetry coverage within the shallow intertidal zone.

# 2   Survey Vessel and Crew

The Survey Vessel (S/V) *Soundwave*, a 26-foot custom aluminum survey boat, owned and operated by Northwest Hydro Inc. (NWH), was deployed for the project (both 2019 and 2020 bathymetric surveys). This vessel is equipped with an integrated navigation/data acquisition system and a custom mount for the R2Sonic 2022 multibeam sonar. This hydrographic survey system is ideal for shallow-water survey operations in tight quarters such as the LDW.

# 3   Positioning

Horizontal positions were acquired with an Applanix POS/MV combined inertial real-time kinematic global positioning system (RTK GPS) navigation system. This system integrates two GPS receivers with a motion reference unit. Additionally, RTK GPS corrections were input into the system to improve horizontal positioning accuracy to better than 0.5 meter (1.6 feet). The advantage of this system is that it not only provides motion information (i.e., heading, roll, pitch, and heave) to compute X, Y, Z data from the multibeam sonar measurements, but it also provides accurate inertial navigation through GPS outages for up to 30 seconds. Position data were used in real time to provide navigation information to the vessel operator. To check the accuracy of the positioning system and confirm the RTK corrections, a position check was conducted daily on an established monument with a known position. Water level measurements were obtained by RTK GPS during data acquisition. Water surface elevations obtained by RTK GPS were verified against gauges placed within the project area, and with an automated water level gauge deployed by NWH within the project area for the duration of data collection. All soundings were reduced to MLLW elevations in the delivered data set.

# 4   Multibeam Data Acquisition

Soundings were acquired with a R2Sonic 2022 high-resolution multibeam bathymetric sonar. Using a frequency of 450 kHz, the R2Sonic sonar illuminates up to a 160° (80° to starboard and 80° to port) by 1.0° swath along the riverbed, perpendicular to the ship's track, and resolves a slant-range measurement to the riverbed every 1.0° along the swath. Sonar ping rates vary, depending on the depth of the water and sonar range settings, but generally were at a minimum rate of 17 Hz as the vessel surveyed along each track line.

Multibeam data were collected by running lines parallel with the shorelines and dock structures. During survey operations, all lines offshore of the shoreline had the sonar swath width limited to a maximum of 60° on both starboard and port beams during processing.

To account for survey vessel heave (vertical movement), pitch, and roll, an Applanix POS/MV motion reference sensor was utilized. The POS/MV system was also used to record vessel heading (yaw) from which the sonar beam orientation is derived. Multibeam data were acquired with Hypack Hysweep data acquisition software. Hysweep acquires and time-tags all sensor data, including multibeam sonar, position, heading, heave, pitch, and roll. The navigation system provides navigation output to the vessel operator's monitor and manages the survey data collection.

Detailed measurements of the sound-velocity profile (SVP) through the water column are critical in multibeam surveys. Sound-velocity profiles were measured at 0.5-meter depth intervals, from the water surface to the mudline, in the part of the survey area with the deepest water. Changes in the

SVP not only affect acoustic distance measurements but can also cause refraction, or bending of the sonar path, as it passes through layers in the water column at different velocities. Because the velocity of sound is directly related to the density and temperature of water, changes in the SVP are expected to occur in the LDW due to the mixing of fresh and saltwater during tidal changes. For this survey, an AML BaseX2 sound-velocity profiler was used to directly measure SVPs of the water column. The SVP has spatial and temporal variations, and to account for these variations, the LDW survey area was divided into subsections. The size of the survey subsections was determined at the time of surveying by collecting SVP data and adjusting the length of a subsection so that similar results were obtained at each end. Temporal change was addressed by taking SVP measurements as each section was mapped.

Data acquisition involves setting the motion sensor to the survey conditions and running slow, uniform lines in a systematic pattern. Adjustments were made to scale and gain settings, as required, to maximize resolution of the survey. During the survey, preliminary multibeam bathymetric data were displayed in real time on the Hypack computer. A real-time color matrix was drawn on the vessel's computer screens to show data coverage. Bathymetry data acquisition was strategically planned to collect shallow-water data during daily high tide events to maximize the amount of high-resolution multibeam sonar coverage of the project area.

# 5  Single-Beam Data Acquisition

Single-beam data were only collected in 2019 and complied with the Survey QAPP. The 2020 bathymetric survey to fill in data gaps only utilized multibeam survey methods.

# 6  Data Processing Methods

Post-processing of multibeam data in 2019 and 2020 was completed using Hypack Hysweep multibeam editing and analysis software. Patch test data were analyzed, and any alignment corrections were applied. Water level data were verified and applied to adjust all depth measurements to MLLW. SVPs were generated from the AML SVP measurements taken in the field and used to correct slant range measurements and compensate for ray path bending.

Processing began with a review of each survey line using the Hysweep swath editor. Verified water surface correctors were applied to the data set at this time. Position and sensor data were reviewed by qualified surveyors and accepted or removed if erroneous data were observed. Sounding data were reviewed and edited to remove bad data points such as bottom multiples or sonar returns from pilings. After swath editing, all data were reviewed through the Hysweep area-based editing tools to ensure no erroneous data points remained.

To take advantage of the level of detail the multibeam survey provides, a 1-foot resolution sun-illuminated model and 1-foot gridded data set were exported from Hysweep. This gridding process uses an inverse weighted mean of all soundings within a 1-foot by 1-foot cell. The 1-foot grid size allows for comparisons with previous bathymetric surveys that were conducted with similar high-resolution methods. The final accepted bathymetry data were imported into Autodesk Civil 3D for generation of a project digital terrain model and 1-foot contours.

# 7   Quality Control and Survey Accuracy

The acquisition system and survey protocols were designed with some redundancy to demonstrate that the required accuracy is being achieved during data acquisition. The following control methods and survey accuracies comply with the Survey QAPP (Anchor QEA and Windward 2019) and were used for both the 2019 and 2020 bathymetric surveys.

**Positioning:** Positions were logged in WGS84 geographic coordinates and projected onto NAD83/91 Washington North Zone coordinate system. A geodetic control survey was conducted to provide positions for monuments within the study area. A position confidence check was conducted daily on a monument that is accessible from the water. Measured positions obtained during these checks were compared to the surveyed value to assure the target horizontal and vertical accuracies were being obtained.

**Tides and Water Elevations:** RTK GPS-derived water levels were checked daily by observing NWH staff gauges that were installed in the project area. The water level checks were made twice per day. Backup tidal observations from NWH deployed automated gauge that were used to confirm the RTK GPS tidal values.

**Patch Test:** To confirm alignment of the sensor data with the sonar swath and verify delay times applied to the time-tagged sensor data, a patch test was conducted. A patch test is a series of lines run in a specific pattern that are used in pairs to analyze roll, pitch, and heading alignment angles with the sonar swath, as well as latency (time delays) in the time tagging of the sensor data. A bar check and lead line check were conducted to confirm draft of the sonar head. These tests were conducted at the beginning and end of the survey and any time there were changes in the instrument configuration.

**Sonar Draft:** A bar check was conducted at the beginning and end of the project to confirm multibeam and single-beam sonar transducer draft below the water line. A bar was lowered below the sonar to specific intervals below the water surface, using calibrated marks on the attached chain. Onboard sonar depth measurements were confirmed to match the known depth of the bar.

**Survey Accuracies:** Bathymetry data were acquired to the USACE specification for soft-bottom dredge surveys (USACE 2013), which states an accuracy of +/- 0.5 foot vertically and 3 feet horizontally for 95% of all data points. These accuracies meet the approved Survey QAPP requirements. Our QA/QC checks during data collection indicate better accuracies were achieved.

# 8   References

Anchor QEA and Windward (Anchor QEA, LLC, and Windward Environmental, LLC), 2019. Quality Assurance Project Plan: Pre-design Surveys of the Lower Duwamish Waterway Upper Reach. Final. Seattle, WA.

USACE (U.S. Army Corps of Engineers), 2013. Engineering and Design: Hydrographic Surveying. EM 1110-2-1003. Department of the Army, November 2013.